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NASA CASE NO. NPO-17, 207-100

PRINT FIG. 1

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(NASA-Case-NPC-17207-1-CU) LOW-LOSS,
EIGH-ISCIATION, FIBER-CPTIC ISCIATOR Patent
Application (NASA) 11 p CSCL 20F

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LOW-LOSS, HIGH-ISOLATION, FIBER-OPTIC ISOLATOR

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Laboaratory March 31, 1988

AWARDS ABSTRACT

The invention relates to a low-loss and high-isolation isolator for use in single-mode fiber-optic systems, and more particularly to a fiber-optic isolator having a measured forward loss of 2.6 dB and improved isolation to greater than 70 dB.

A low-loss, high-isolation, fiber-optic isolator shown in FIG. 1 uses an isolator assembly 16 comprised of a Faraday rotator 19 and two polarizers 17 and 18, one at each end angularly oriented from each other at the angle of rotation of the Faraday rotator for isolation, and two aspheric lenses 20 and 22 with ferrules 21 and 23 to connect optical fibers 14 and 15 to the isolator assembly. The system improves isolation to greater than 70 dB. The apertures into the system are defined by the optical fibers interfacing with the flat surfaces of the lenses. Incident light is expanded by the lens 20 and collimated into the isolator assembly. At the exit end, the lens 21 focuses the collimated beam into the aperture of the fiber 15. Light reflected in the isolator assembly is rejected by the small acceptance angles and apertures of the aspheric lenses. FIG. 2 is a graph of excess transmission loss (dB) as a function of distance between aspheric lens connectors. FIG. 3 is a graph of transmission loss between aspheric lens connectors as a function of offset angle.

The novelty of the invention resides in the use of aspheric lenses at each end of an optical isolator assembly to provide small apertures and acceptance angles for rejection of reflected light within the isolator assembly.

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Pasadena	CA.	91109
(City)	(State)	(Zip)

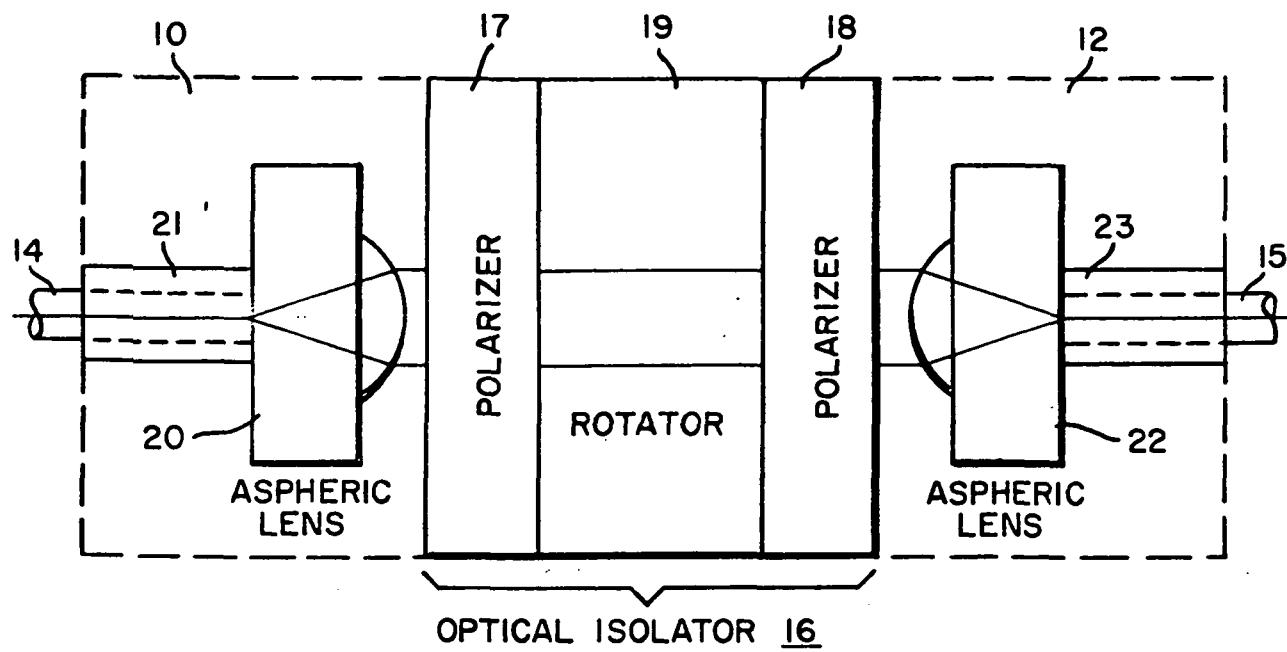


FIG. 1

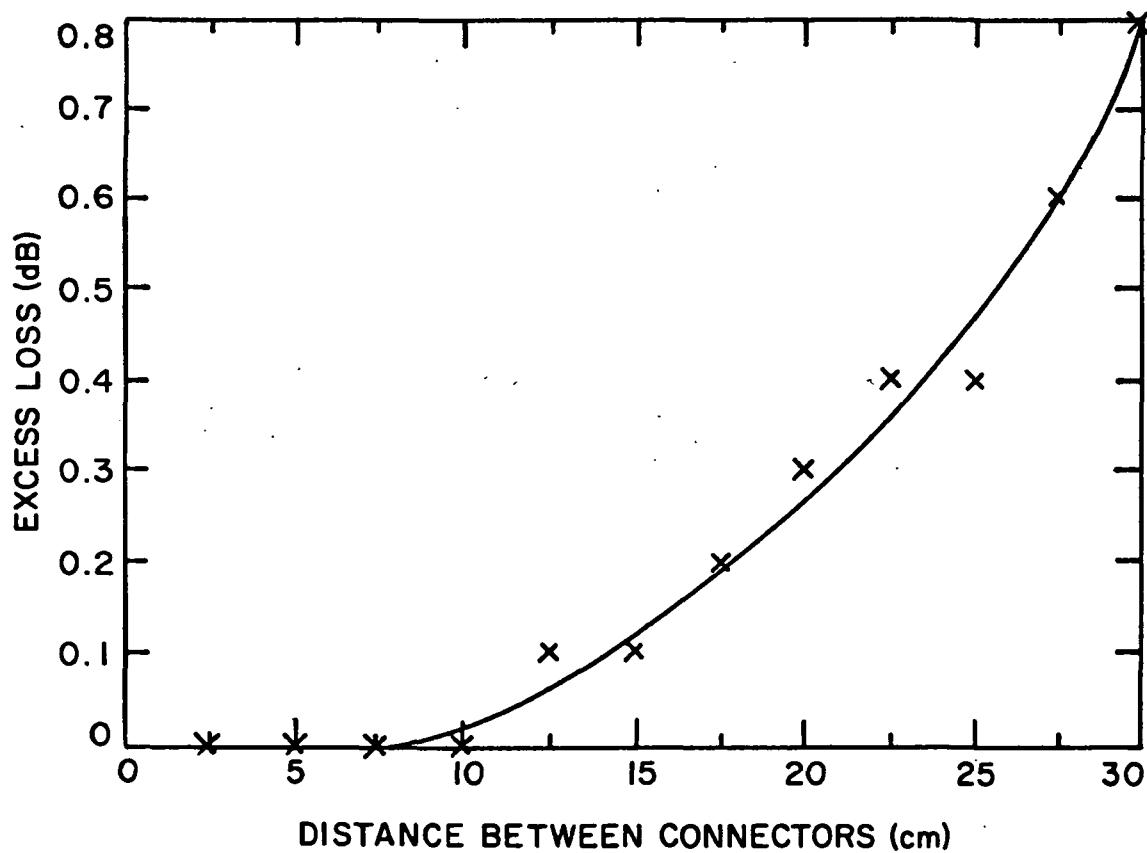


FIG. 2

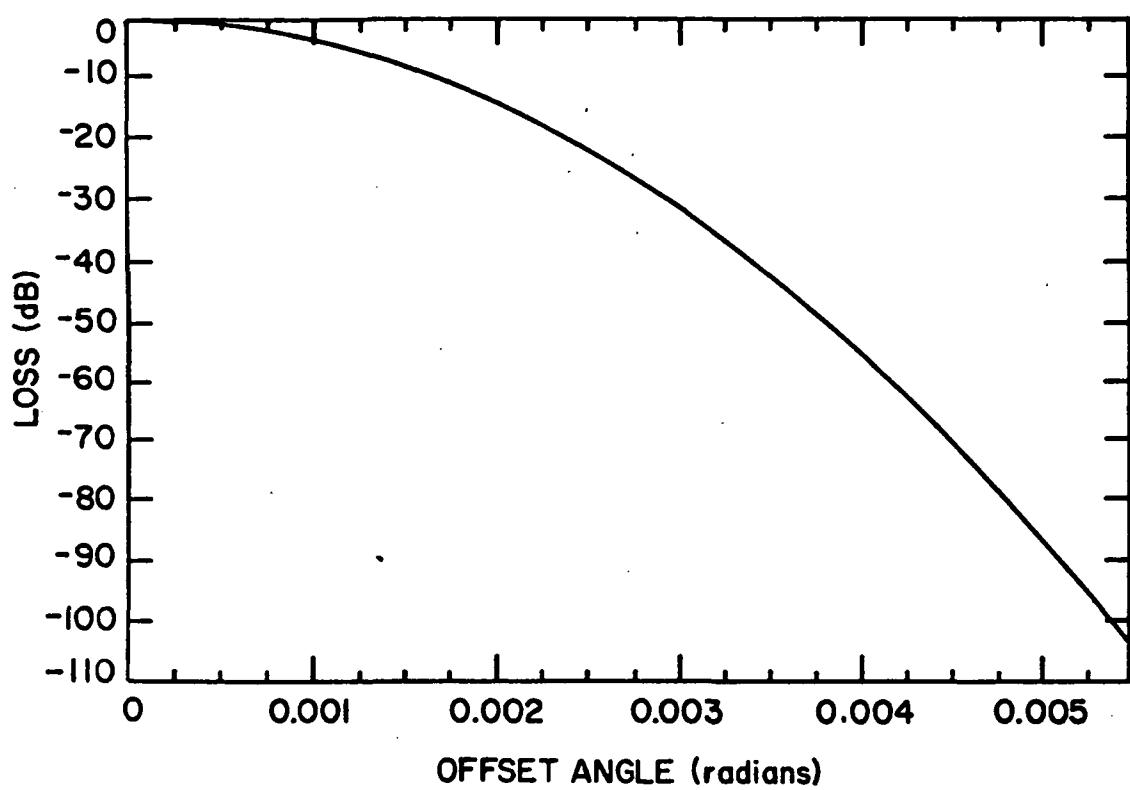


FIG. 3

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Contractor	PATENTch/JPL	
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LOW-LOSS, HIGH-ISOLATION,
FIBER-OPTIC ISOLATOR

Origin of the Invention

5 The invention described herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 USC 202) in which the Contractor has elected not to retain title.

10 Technical Field

The invention relates to a low-loss, high-isolation, fiber-optic isolator for use in single-mode fiber systems, and more particularly to an isolator having a measured forward loss of 2.6 dB and improved isolation to greater than 70 dB.

15

Background Art

20 Reflections cause intolerable instabilities in fiber-optic systems used in some precision applications, such as precise reference frequency distribution and microwave transmission. The reflections have the same effect on a semiconductor laser source as an unstable external cavity, and causes changes in the laser's output wavelength and amplitude. In some systems, external reflections must be reduced by 60 dB or more before the resulting instabilities are reduced to tolerable levels.

25 Optical isolators are currently used to alleviate this problem. However, the best single-mode fiber-optic isolators which have been reported have losses of 3 or 4 dB and isolation of 30 to 40 dB. (See Okamoto, K., Miyazawa, H., Noda, J., and Saruwatari, M., "Novel optical isolator consisting of a YIG spherical lens and PANDA-fiber polarizers," Elect. Lett., 1985, 21, pp. 36-38; Green, A.E., Georgiou, G., "Compact bulk optical isolator with monomode fibre pigtailed for use at 1.3," Elect. Lett., 1986, 22, pp. 1045-1046; and Gauthier, D.J.,

Narum P., Boyd, R.W., "Simple, compact, high-performance permanent-magnet Faraday isolator," Optics Lett., 1986, 11, pp. 623-625. It is necessary to use two such isolators in series to obtain the isolation of greater than 60 db required in some 5 fiber-optic systems, such as those used for precise reference frequency or microwave frequency distribution.

There are disadvantages in using two isolators in series: good optical isolators are very expensive, and the forward loss is increased.

10

Statement of the Invention

Accordingly, it is an object of this invention to provide an optical isolator with greater than about 70 dB isolation of reflected light from a source and less than about 3 dB 15 loss in the forward direction.

The low-loss and high-isolation apparatus of this invention is comprised of an isolator assembly consisting of a Faraday rotator and polarizers on each side oriented with respect to each other at an optimum angle between their directions of polarization equal to the rotation angle of the 20 rotator, and two aspheric lenses facing each other, one on each side of the isolator assembly.

Each of the aspheric lenses has an aspheric surface facing the isolator assembly and a planar surface on the 25 outside. Together with the isolator assembly positioned in a gap of several centimeters between the aspheric lens, the aspheric lenses permit light to be transmitted with low loss and high isolation from one side to the other by accepting incident light through small apertures and expanding the light 30 to collimated beams larger than the apertures, and providing a small acceptance angle and small aperture to reflected light within the isolator assembly.

The novel features that are considered characteristic of this invention are set forth with particularity in the

appended claims. The invention will best be understood from the following description when read in connection with the accompanying drawings.

5 Brief Description of the Drawings

FIG. 1 is a schematic block diagram of the present invention.

FIG. 2 is a graph of excess transmission loss (dB) as a function of distance between aspheric lens connectors (cm).

10 **FIG. 3** is a graph of transmission loss between connectors as a function of offset angle.

Detailed Description of the Invention

FIG. 1 is a schematic drawing of the invention comprised of two aspheric lens connectors 10 and 12 for optically coupling to the ends of single-mode optical fibers 14 and 15. Positioned between the connectors is an optical isolator 16 comprised of two polarizers 17 and 18 oriented at an optimum angle α from each other, depending on the angle of rotation of a transparent isotropic medium 19 having a Verdet constant ω in a magnetic field of strength H . The angle α of rotation is equal to $\alpha = \omega l H$, where l is the length of the path traversed through the medium. The connectors 10 and 12 consist of aspheric lenses 20 and 22, and ferrules 21 and 23 on flat sides opposite the aspheric surfaces. The flat surfaces are oriented parallel to planar surfaces of the isolator 16 in order to align the axes of the lenses parallel to each other and with minimum lateral offset from each other.

The organization of the low-loss, high-resolution, 30 single-mode fiber-optic isolator shown in FIG. 1 will now be described in terms of the functions of the components. The isolator 16 is essentially generic and is the primary means for isolation between the fibers 14 and 15. The isolator used in this assembly is a model IO-4-IR manufactured by Optics For 35 Research, Box 82, Caldwell, New Jersey 07006, who manufactures

a variety of optical isolators using the Faraday rotator principle. The model used is designed for 1300 nm operation and has an aperture of 4 mm. Isolation is specified as greater than 30 dB. One better than about 40 dB has not heretofore 5 been known. Forward loss is specified to be less than 0.5 dB.

As noted hereinbefore, such an isolator is not sufficient. Two such isolators in series would normally be required for isolation greater than 60 dB, but forward loss is then apt to be greater than 3 dB. Accordingly, only one such 10 isolator is used with the connectors 10 and 12 one on each end of the isolators facing each other. These connectors permit light to be transmitted with low loss from the single-mode optical fiber 14 to the single-mode optical fiber 15 with a gap of several centimeters between them. A plot of the optical 15 loss as a function of the distance between connectors is shown in FIG. 2. The connectors are placed an appropriate distance for the optical isolator to be installed between them.

The aspheric lenses 20 and 22 are shaped to convert a 20 beam entering through a small aperture (diameter of the optical fiber) into a larger columnar beam, and are provided with the ferrules 14 and 15. These aspheric lenses with ferrules attached are commercially available from Lamdek Fiber Optics, a division of Eastman Kodak Company. The lenses are made of 25 glass to facilitate mass production, to render them capable of excellent performance over a broad range of environmental conditions (temperature, humidity, etc.), and to provide long life operation (20 years). Flat surfaces are provided around the aspheric surfaces of the lenses 20 and 22 which are parallel 30 to their planar surfaces in order to facilitate aligning the axes of the two connectors to within less than 15 seconds of arc. Means (not shown) are provided to maintain the connector and isolator assemblies together, and in alignment with the isolator. Such means may include precision steel balls 35 between the surrounding flat surfaces of the lenses and the

planar surfaces of the isolator, as suggested by Lamdek Fiber Optics. The isolator surfaces should also be aligned perpendicular to the connector axes with the same degree of accuracy. Once aligned angularly, the axis of one connector 5 through the isolator assembly should be adjusted to a minimum, within 0.05 mm lateral displacement. This angular and lateral alignment is important because the function of the connectors 10 and 12 is to virtually eliminate internal reflections by providing the small apertures and acceptance angles needed for 10 high isolation by the Lamdek connectors.

Each aspheric lens is ideally provided with an aspheric surface that is an ellipse of revolution with a conic constant $K = 1/N^2$, where N is the index of refraction of the lens material (glass) to eliminate spherical aberration in the beam 15 entering the connector 10 as it is transmitted through the connector 12. Aspheric lenses are reported by the manufacturer to eliminate over 0.4 dB insertion loss, as compared to spherical lenses. They are used in the present invention in order to transmit a substantially collimated 1.5 mm beam 20 through the isolator 16, and then to refocus the beam to a small aperture (9 μm diameter) of the fiber 15. As the beam enters the isolator 16, it is polarized in a particular direction. That direction is then rotated through an angle α by the rotator 19, and the rotated and collimated beam is then passed 25 through the polarizer 18 having its direction of polarization oriented at the angle α in respect to the polarization direction of the polarizer 17. The connectors 10 and 12 virtually eliminate all reflections at the ends of the fibers 14 and 15 by providing a small aperture at their interfaces with the 30 planar back of the aspheric lenses.

The theory of operation of the low-loss, high-isolation, fiber-optic apparatus of **FIG. 1** will now be further described, but first it should be recalled from the discussion of the background art that reflections cause instabilities in 35 fiber-optic systems which are intolerable in some precision

applications, such as precise reference frequency distributions and microwave transmission. Reflections have the same effect on a semiconductor laser source as an unstable external cavity, and causes changes in the laser's output wavelength 5 and amplitude. In some systems, external reflections must be reduced by 60 dB or more before the resulting instabilities are reduced to tolerable levels.

The isolator 16 has much greater isolation potential than expected. However, the isolation reported previously by 10 the manufacturer of the isolator 16 was evidently limited by scattering due to internal reflections. The polarization of this scattered light at various locations within the isolator 16 is not in the direction required for high attenuation. Consequently, such scattered light was a problem in achieving 15 the full potential of the isolator. A secondary problem is the nonuniformity of the polarizers across their diameters. The polarizers have a much higher extinction ratio when the optical beam size is smaller because they are more uniform across a small area.

20 Fortunately the scattered light, which limits the isolation, is not parallel to the axis of the isolator assembly 16 when it exits. Therefore, it can be virtually eliminated by collecting the optical output of the isolator assembly 16 using a lens with a small aperture and small 25 acceptance angle. The aspheric lenses 20 and 22 provide such a small aperture (9 μm at the interface with the optical fibers 14 and 15) and a small acceptance angle needed for high isolation. Thus, when used on both sides of the isolator, these aspheric lenses set the collimated beam diameter through 30 the isolator assembly 16 by expanding the beam from an input aperture of 9 μm diameter to about 1.5 mm in diameter. The isolator assembly 16 presents the collimated beam to a 9 μm aperture at the output of the aspheric lens 22 through a small acceptance angle for high isolation.

The transmission loss in dB of optical power at the receiving connector is related to the offset angle of a light beam or ray by

$$\text{Loss} = 20 \log [e^{-(f\theta n\omega_0)^2}],$$

5 where f = the focal length of the lens = 7 mm,

θ = the offset angle (radians),

n = the index of refraction = 1.4995, and

ω_0 = 1/2 the mode field diameter = .00523 mm.

10 A plot of transmission loss as a function of the offset angle is shown in FIG. 3. At an angle of .0045 radians the loss is 70 dB. This accounts for the extremely large rejection of scattered light coming out of the optical isolator.

15 A low-loss, high-isolation fiber-optic isolator assembled as described has been measured for loss and isolation and found to be 2.6 dB and greater than 70 dB, respectively. These results were achieved using commercially available components. The availability of such high quality single-mode fiber-optic isolators will make it possible to achieve substantial improvements in precision fiber-optic systems such as 20 those used for stable reference frequency distribution and microwave frequency transmission.

25 Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art. Consequently, it is intended that the claims be interpreted to cover such modifications and variations.

LOW-LOSS, HIGH-ISOLATION,
FIBER-OPTIC ISOLATORABSTRACT OF THE DISCLOSURE

A low-loss, high-isolation, fiber-optic isolator for
5 use in single-mode fiber systems utilizes a Faraday rotator
and two polarizers, one at each end angularly oriented from
each other at the angle of rotation for isolation, and two
aspheric lens connectors to couple optical fibers to the
Faraday isolator to reduce forward loss to about 2.6 dB and
10 improve isolation to greater than 70 db.